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PREDICTING MAJOR STREET TRAFFIC VOLUMES IN SMALL CITIES

A THESIS

Presented to

the Faculty of the Graduate Division

by

David Warren Wright

In Partial Fulfillment

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and

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# PREDICTING MAJOR STREET TRAFFIC VOLUMES IN SMALL CITIES

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## CHAPTER I

### INTRODUCTION

In recent years traffic volumes on streets and highways in urban areas have been rapidly increasing. This is due to both a shift of population to urban areas and an increase in vehicle ownership. In 1860 only twenty per cent of the United States' population resided in urban areas. By the turn of the century, the percentage had risen to forty, and today, two out of three Americans live in urban areas (1). Since World War Two vehicle ownership rates have been on the increase. In 1948 there was one car for every 4.8 persons. By 1955 there was one car for every 3.3 persons and a conservative estimate for 1975 is one car for every 2.5 persons (2).

This growth in traffic volumes has created many new congestion problems and aggravated existing ones. Construction of new streets and highways and improvement of existing ones to solve these congestion problems are very expensive. Furthermore, once improvements are made they may be expected to last at least 20 to 30 years. Therefore, planning of these facilities should be based on an accurate prediction of future traffic.

In many of the large metropolitan areas, transportation studies have been made by well trained staffs in which sound methods of predicting traffic have been developed. However, very few transportation studies in small cities have developed reliable estimates of future traffic. A study made by Richard C. Cowdery, Director of the Urban Transportation Planning Service for the American Municipal Association, states that transportation planning in small cities is virtually non-existent (3).

The purpose of this thesis is to examine the applicability to small cities of the methods of predicting traffic volumes on streets and highways that were developed in the large metropolitan areas. Chapter Two will present the Fratar method and Chapter Three will present the mathematical model method. In these chapters the various steps necessary in utilizing each method in a small city will be discussed.

For the purposes of this study a small city is defined as one having a population of less than 100,000. It will be assumed in cities of this size that trips made by mass transit are negligible when compared with trips made by private vehicles. Therefore, the term trip as used in this study will refer to an auto trip.

The information for this study was obtained from transportation studies made in various cities, from a review of reports made by researchers in the urban transportation planning field, from a review of other pertinent literature on the subject of traffic prediction and by personal interviews.

## CHAPTER II

### FRATAR METHOD OF PREDICTING FUTURE TRAFFIC

This chapter will present one of two possible methods of predicting future street traffic in an urban area. This method utilizes the Fratar technique for distributing future street traffic. The Fratar technique was developed by Thomas J. Fratar and his associates while preparing a highway plan for Cleveland, Ohio in 1953.

In considering the use of the Fratar method the following three points are important. First, the use of the Fratar method requires a complete origin and destination study. Second, the Fratar method does not yield good results in cities which have large undeveloped areas that are expected to be developed in the future. Third, due to the volume of the mathematical computations required in utilizing the Fratar method, it is necessary that these computations be made on a computer. Computer programs which make the Fratar method computations have been written for most computers available today.

The various steps of the Fratar method are: (1) land use survey; (2) origin and destination survey; (3) trip

generation; (4) land use forecast; (5) distribution of inter-zonal trips and (6) traffic assignment.

#### Land Use Survey

For traffic prediction purposes a land use survey should include the following:

1. a recording of the kind of land use for each parcel of land;
2. a recording of the intensity of land use for each parcel of land; and
3. a recording of the approximate number of acres of each parcel of land.

The land use survey should be conducted by a trained city planner.

For analysis purposes the various uses of land should be classified. In large metropolitan area transportation studies land use classification systems with a large number of detailed land use categories have been used. It is the opinion of the author that such a highly detailed classification system is not warranted because land use cannot be realistically forecast in such detail. A minimum classification system should include residential, commercial, industrial, and vacant land as categories. However, land use

classifications should be as detailed as necessary to reflect any distinct differences in the trip generating ability of land uses. For example, in residential areas it is often necessary to have separate classifications for apartment dwelling unit areas and single family dwelling unit areas.

The kinds of land uses are usually recorded by an inspection of aerial photos supplemented by a field inspection.

A recording of the intensity of land use should also be made. Both the use and the intensity of land use on a site affect its trip generating ability. Measures of intensity for the various categories of land use are:

1. for residential land, dwelling units per acre;
2. for commercial land, employees per acre and square feet of floor space per acre; and
3. for industrial land, employees per acre.

The number of dwelling units in residential areas should be determined from aerial photos and census publications, and should be supplemented by field checks.

Information on the number of employees in each major establishment is usually available from industrial development and chamber of commerce organizations. These data can be supplemented by telephone interviews with firms that are not listed by the above organizations.

In most cities floor space data can be estimated from Sanborn Insurance maps. In areas where these maps are not available, floor space data can be estimated by a field inspection or from aerial photos.

### Origin and Destination Survey

The origin and destination survey is used to determine the originating and terminating points of trips. The origin and destination survey should be made by a trained traffic engineer.

The first step in the origin and destination survey is the division of the urban area into zones to obtain workable units for data analysis. Zones should be delineated as follows:

1. Land use within a zone should be homogeneous.

Different classifications of land use generate traffic at different rates. Fewer computations will be necessary in the following steps of the Fratar method if each traffic zone contains only one of the classifications of land use. As a corollary to this point the central business district should constitute a single zone.

2. The shape of a zone should be square or circular. Irregular shaped zones should be avoided. All trips are assumed to originate and terminate at the center of the zone. The center of the zone is most representative of complete area of the zone when it is square or circular.
3. Whenever possible traffic zone boundaries should correspond to boundaries of enumeration districts or census tracts. The maximum use of census data can be made if traffic zones and census tracts or enumeration districts correspond.
4. Zones should be made as large as possible without generating more than 10,000 trips per day. Studies have shown in general that when zones generate more than 10,000 trips per day they are too large to accurately represent the location of trip origins and destinations (4). To meet this criteria zone size should vary in proportion to the intensity of land use within the zone. Two reasons why zones should be as large as possible



and still remain within the above criteria are: (1) land use cannot be accurately forecast for small areas; and (2) the number of computations required to distribute trips by the Fratar formula is proportional to the square of the number of zones.

In a practical situation it will be difficult to meet all of the above criteria. Therefore, compromises will have to be made in these criteria to establish workable units for traffic prediction purposes.

The parts of an origin and destination survey recommended by the National Committee on Urban Transportation to be conducted in a small city are the external cordon survey, the internal cordon survey, and the home interview survey (5).

#### External Cordon Survey

The external cordon survey is a roadside interview study in which a sample of drivers is stopped and questioned as to the origin, destination and purpose of their trips. The interviews are conducted on an external cordon line which is an imaginary line drawn around the outer limits of the urban area. It is recommended that fifty per cent of the drivers be interviewed on a cluster sampling basis (6). For example, four vehicles should be interviewed and four

vehicles should be passed. The number of vehicles in each cluster will be determined by the number of interviewers in the survey party. A typical party might include: (1) a party supervisor; (2) six interviewers; (3) two flagmen; and (4) a police officer. It is recommended that the survey be conducted from 6:00 A. M. to 10:00 P. M. for one day, preferably a Tuesday, Wednesday or Thursday. In addition, the time of year selected to conduct the survey should be one in which traffic volume is not abnormal. This type of survey produces data on the number of trips which have trip ends outside the external cordon line. The cost of this type of survey is approximately \$1500.00 per station.

#### Internal Cordon Survey

The internal cordon survey is another roadside interview study in which drivers are questioned as to their trip origin, trip destination and trip purpose. Interviews for this survey are made on an internal cordon line which surrounds the central business district. The sampling technique, the type of personnel included in the party, and time of survey are the same for this type survey as they are for the external survey. However, since the traffic volume passing stations on the internal cordon will be greater than that on the external cordon more interviewers will be needed.

This type of survey provides data on the number of trips which enter or leave the central business district. The cost of this type of survey is approximately \$2000.00 per station.

#### Home Interview Survey

In conducting a home interview survey, interviews are made at a sample of the dwelling units in the urban area. It is recommended that one out of every five dwelling units be sampled in small cities (7). In the interview the occupants of the dwelling unit are questioned as to the origin, destination and purpose of all trips made on the previous day. The cost of a home interview survey is approximately \$1.75 per interview (8).

Two alternate methods of gathering information on trips made from the home are the postcard survey and the telephone survey.

The postcard survey is a method of obtaining origin and destination data in which each registered vehicle owner in the area is mailed a self-addressed prepaid postcard questionnaire. The owner is asked to list all trips by address of origin, address of destination and trip purpose made by his vehicle on the day after receipt of the card. The cost of this type of survey is approximately \$1.00 per card returned. Approximately thirty per cent of the cards

mailed are usually returned. Although this method yields a larger sample of data at a savings of time and money it has three disadvantages. First, the questionnaire must necessarily remain simple, therefore, the data gathered are less detailed than those gathered by the home interview survey. Second, vehicle registration records may not be available for the area considered in the study. Finally, the questionnaire returned may be biased in that certain occupational groups have a greater tendency to return mail than do others. However, the conclusion of a study made comparing the results of the home interview survey and the post-card survey was that the results obtained from the two surveys were approximately the same (9).

The telephone interview survey is a method of obtaining origin and destination data through telephone conversations with a random sample of residents. Telephone numbers are selected from the directory at random excluding business and double listings. A twenty per cent sample is recommended for this method. Members of the households called are questioned as to the origin, destination and purpose of trips made on the day preceding the interview. A letter should be sent to all interviewees a few days before the survey in order that they can be prepared to answer

the questions. The cost of this survey is approximately \$1.00 per interview. This type of survey may also be biased in that households not listed or not owning a telephone may have different travel habits than those interviewed. However, in areas where this method has been used this bias has not seriously affected the final results (10).

The results of the origin and destination survey are: (1) the existing number of trips originating and terminating in each zone (trip ends); (2) the existing number of trips made between each pair of zones (interzonal trips); and (3) the purpose of the existing interzonal trips.

#### Trip Generation

The next step in predicting future traffic is to determine the relationship between the number of trips originating and terminating (trip ends) in traffic zones, and land use and land use intensity. Once these relationships are determined they can be applied to a forecast of future land use and land use intensity to determine the future number of trip ends in each zone. For example, a relationship can be derived which expresses the number of trip ends that will be generated per employee in an industrial zone. If this relationship is assumed to be constant through time,

the future number of trip ends in that industrial zone can be determined by estimating the future number of employees in the zone.

These relationships are usually determined by simple regression analysis. This is a statistical technique in which a mathematical relationship is derived. For instance, the relationship between the number of trip ends and the number of employees in industrial zones could be analyzed by simple regression analysis as follows. First, land use intensity data and origin and destination data are examined. Next, the number of trip ends and the number of employees in each zone are plotted on a graph. The resulting graph might look similar to the one shown in Figure 1 on page 15. This is called a scatter diagram.

The scatter diagram can then be analyzed mathematically to determine the curve which represents the relationship between trip ends and employees most accurately. Such a curve is called a regression curve or a curve of "best fit". Assuming that in the case of the scatter diagram shown in Figure 1 the mathematical analysis showed that the relationship between trip ends and employees is best represented by a straight line, the regression line would appear as shown in Figure 2 on page 15.



Figure 1. Scatter Diagram

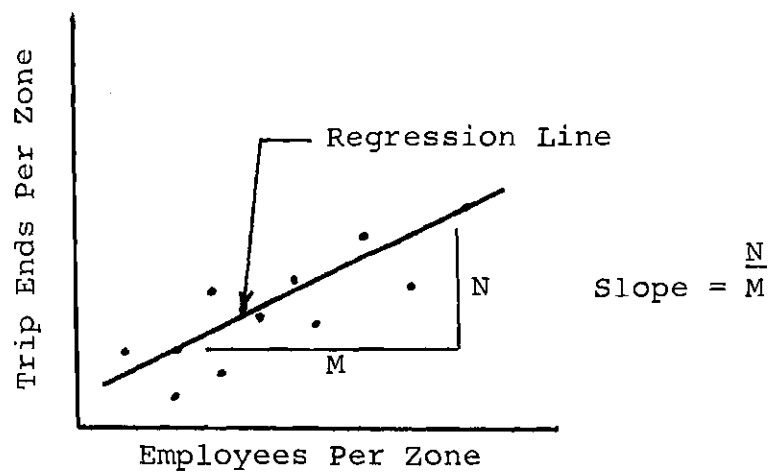


Figure 2. Example of Regression Line

The mathematical form of this regression line ( $y=ax+b$ ) expresses the relationship between trip destinations and employees per zone mathematically. That is:

$y$  = trip destinations per zone;

$x$  = employees per zone;

$a$  = slope of the line (the ratio of trip ends to employees per zone); and

$b$  = the number of trip ends per zone when the number of employees equals zero.

In the example above the relationship was assumed to be best represented by a straight line. However, the mathematical analysis may show that the relationship is best represented by a parabolic, exponential, or other non-linear curve.

The above method should be used to determine the existing relationship between land use intensity and trip ends for each category of land use for each trip purpose.

Since there are literally as many trip purposes as there are reasons for making a trip, trip purposes should be classified. Studies made by the Bureau of Public Roads state that in small cities the use of the following three trip purpose categories have proved to be successful (11).



1. Home based work trips. This group includes those trips made to or from place of residence and place of employment for the purpose of work.
2. Home based non-work trips. This group includes those trips to or from place of residence and any other place for any purpose except work.
3. Non-home based trips. This group includes those trips which have neither origin nor destination at the home.

The relationships which should be determined are as follows:

1. for residential areas the relationship between home based work trip ends and dwelling units;
2. for residential areas the relationship between home based non-work trip ends and dwelling units;
3. for commercial areas a relationship between home based work trip ends and employees;
4. for commercial areas a relationship between home based non-work trip ends and floor space;
5. for commercial areas a relationship between non-home based trip ends and floor space;
6. for industrial areas a relationship between home based work trip ends and employees; and

7. for industrial areas a relationship between non-home based trip ends and employees.

### Land Use Forecast

The future number of trip ends in each zone is estimated from the relationships between land use and land use intensity, and trip ends derived in the previous section. By assuming that these relationships will remain constant through time the future number of trip ends can be estimated if land use and land use intensity in each zone are forecast.

The land use forecast should estimate the number of acres of each land use classification and the intensity of each in each zone. The same classification system used in the land use survey should be used in the forecast. The land use forecast should be made by a trained city planner.

The land use survey should be based on an economic and population study. A study of the area's economy provides information on, among other things, the growth or decline in the various types of industries within the area. From this information the growth or decline in the various types of employment opportunities in the area can be estimated. Having estimated the types of employment opportunities that will be available and by studying past trends in

population an estimate can be made of the future number of families in each income group that will live in the area. If the number of families that will live in the city can be estimated, the future development of land uses to serve these families can also be estimated and hence, the land required by these uses can be derived. Considering, such factors as housing preferences of the various income groups, zoning, availability of utilities, terrain, soil conditions, accessibility, and present development, the areas of the city that will receive future development can be anticipated.

#### Distribution of Interzonal Trips

After the existing number of trip ends in each zone and the present number of interzonal trips have been determined and the future number of trip ends in each zone have been estimated, it will be necessary to distribute the future interzonal trips. A separate distribution of interzonal trips should be made for each trip purpose category.

The Fratar method of distributing interzonal trips is a successive approximation method. Using this method, the future trip ends, both origins and destinations, in each zone are distributed to the other zones, as a first approximation, in proportion to the attractiveness each zone has for trips

relative to the attractiveness of the other zones. The attractiveness of each zone is defined as the existing interzonal trip volume between the zone from which trips are being distributed and the zone in question multiplied by the growth factor of the zone in question. The growth factor for each zone is defined as the future trip ends divided by the existing trip ends. The number of future trip ends in each zone is estimated utilizing the method described in the trip generation section of this chapter. The number of existing trip ends in each zone is determined from the origin and destination survey.

Since growth factors are defined as the future trip ends in a zone divided by the existing trip ends, difficulty is encountered in determining growth factors for zones which are presently undeveloped but are expected to develop in the future. In these zones the existing number of trip ends may be zero. Therefore, if the future number of trip ends is estimated to be other than zero the growth factor will be infinite and the Fratar technique will be unusable.

A procedure has been developed that partially eliminates this disadvantage. It consists of combining zones which are presently undeveloped with neighboring zones which are more stable. The distribution is made using the combined

zones, after which the total trip interchanges of the combined zones are prorated back to each zone in proportion to the future trip ends in each zone.

Since this method distributes total future trips, both coming and going from each zone and since a distribution of trips is made for each zone, the interzonal trip volume between a pair of zones will have two tentative values. For example, between zones A and B the interzonal trip volume will have the value obtained when distributing trips from zone A and also the value obtained when distributing trips from zone B. As a first approximation of the future interzonal trip volume between zone A and zone B these pairs of tentative values are averaged. For each zone the first approximations of the interzonal volume between it and each other zone are added to determine the calculated number of future trip ends. This calculated number of future trip ends estimated in each zone will not always equal the number of future trip ends estimated in the trip generation section. To correct this discrepancy, correction factors are calculated for each zone by dividing the estimated number of future trip ends by the calculated number of future trip ends. Substituting the correction factors

thus obtained for the growth factors and substituting the first approximation of interzonal trip volumes for the existing interzonal trip volumes, the distribution is repeated and a second approximation of the interzonal trip volumes and the correction factors is determined. This process is repeated until the calculated number of trip ends in each zone approximately equals the estimated future trip ends.

In summary, the steps in distributing trips by the Fratar method and a simple example illustrating the use of these steps will be presented.

Consider the simple three zone situation shown in Figure 3 on page 23 and the known data for this situation tabulated in Table 1.

Table 1. Known Data for Example Situation

Zone	Existing Trip Ends	Estimated Future Trip Ends	<u>Existing Interzonal Trips</u>	
			Between Zones	Number of Trips
A	50	50	A-B	30
B	40	80	B-C	10
C	30	90	A-C	20

Existing Trip Ends  
Equal 50

Existing Trip Ends  
Equal 40

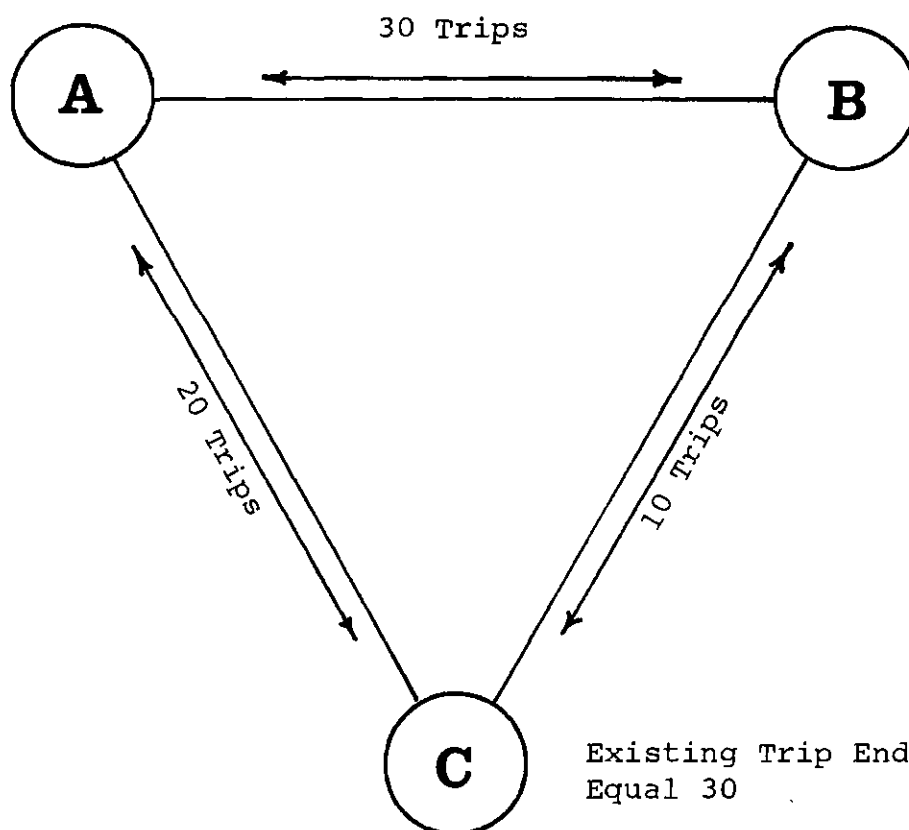


Figure 3. Distribution of Existing Trips

The following steps are used to distribute future interzonal trips.

1. Determine the growth factor for each zone by dividing the estimated future trip ends by the existing trip ends.

The growth factors for the example will be as follows:

$$\text{Growth Factor Zone A} = \frac{50}{50} = 1.0$$

$$\text{Growth Factor Zone B} = \frac{80}{40} = 2.0$$

$$\text{Growth Factor Zone C} = \frac{90}{30} = 3.0$$

2. Determine the attractiveness each zone has for attracting trips from each other zone by multiplying each existing interzonal trip volume by the zone's growth factor.

Attractiveness values for the example are as follows:

$$\text{Zone A for Zone B} = 30 \times 1 = 30$$

$$\text{Zone A for Zone C} = 20 \times 1 = 20$$

$$\text{Zone B for Zone A} = 30 \times 2 = 60$$



$$\text{Zone B for Zone C} = 10 \times 2 = 20$$

$$\text{Zone C for Zone A} = 20 \times 3 = 60$$

$$\text{Zone C for Zone B} = 10 \times 3 = 30$$

3. Determine the proportion of the future trip ends in each zone that will be distributed to each other zone by dividing the attractiveness value of the zone to which trips are being distributed, by the sum of the attractiveness values of all the zones which have an interchange with the zone in question.

The proportion of future trip ends from each zone to each other zone in the example is:

$$\text{From Zone A to Zone B} = \frac{60}{60 + 60} = .50$$

$$\text{to Zone C} = \frac{60}{60 + 60} = .50$$

$$\text{From Zone B to Zone A} = \frac{30}{30 + 30} = .50$$

$$\text{to Zone C} = \frac{30}{30 + 30} = .50$$

$$\text{From Zone C to Zone A} = \frac{20}{20 + 20} = .50$$

$$\text{to Zone B} = \frac{20}{20 + 20} = .50$$

4. Determine the number of future trips that will be distributed from each zone to each other zone by multiplying the number of future trip ends in each zone by the proportion of trip ends going to each other zone as determined in the previous step. This will give two tentative values for each interzonal trip volume.

The interzonal trip volumes for the example are:

From Zone A to Zone B =  $50 \times .50 = 25$

to Zone C =  $50 \times .50 = 25$

From Zone B to Zone A =  $80 \times .50 = 40$

to Zone C =  $80 \times .50 = 40$

From Zone C to Zone A =  $90 \times .50 = 45$

to Zone B =  $90 \times .50 = 45$

5. Determine the first approximation of each interzonal trip volume by averaging the two tentative values found in the previous step.

Averages for the example are as follows:

$$\text{Between Zones A and B} = \frac{25 + 40}{2} = 35.5 \text{ (Say 36)}$$

$$\text{Between Zones A and C} = \frac{25 + 45}{2} = 55$$

$$\text{Between Zones A and C} = \frac{25 + 40}{2} = 42.5 \text{ (Say 43)}$$

6. Determine the calculated number of future trip ends in each zone by adding the first approximation of interzonal trips to or from each zone.

Calculated number of future trip ends for each zone in the example is as follows:

$$\text{Zone A} = 33 + 35 = 68$$

$$\text{Zone B} = 33 + 43 = 76$$

$$\text{Zone C} = 35 + 43 = 78$$

7. Compare the calculated number of future trip ends in each zone with the estimated number of future trip ends in each zone as developed in the trip generation section. If the two values are not approximately equal in each zone, compute a correction factor for each zone by dividing the estimated number of future trip ends by the calculated number of future trip ends.

For each zone of the example the number of calculated and estimated future trip ends is as follows:

Zone	Calculated Future Trip Ends	Estimated Future Trip Ends
A	68	50
B	76	80
C	78	90

As can be seen the number of calculated and the number of estimated trip ends are not approximately equal in each zone. Therefore, the correction factors for each zone are:

$$\text{Zone A} = 50/68 = .74$$

$$\text{Zone B} = 80/76 = 1.06$$

$$\text{Zone C} = 90/78 = 1.15$$

8. Substituting the correction factors obtained in the previous step for the growth factors and substituting the first approximation of future interzonal trip volumes for the existing interzonal trip volumes, repeat steps 2 through 7.

The second approximation yields the following:

Interzonal Trips Between Zones	Calculated Trip Ends In
A and B = 25	Zone A = 55
A and C = 30	Zone B = 81
B and C = 56	Zone C = 86

Using the above data from the second approximation the new correction factors will be:

$$\text{Zone A} = 50/55 = .91$$

$$\text{Zone B} = 80/81 = .99$$

$$\text{Zone C} = 90/86 = 1.05$$

After the second approximation the difference between the known number of trip ends and the calculated number of trip ends in each zone is reduced. This process can be repeated as many times as necessary to get the desired level of agreement between these two values. The third approximation of the number of future interzonal trips and calculated trip ends is:

Interzonal Trips Between Zones	Calculated Trip Ends In
A and B = 22	Zone A = 51
A and C = 29	Zone B = 81
B and C = 59	Zone C = 88

Assuming that in the example the difference between the third approximation of the future trip ends and the estimated future trip ends is insignificant, the interzonal trip volumes derived in the third approximation will be accepted as the future distribution.

#### Traffic Assignment

Traffic assignment is the process of allocating the estimated future trips between each pair of zones to various streets in the transportation system. Traffic assignment is used to test the adequacy of streets to carry the anticipated traffic that will travel on them.

Traffic assignment is based on the premise that a driver will evaluate each route between a pair of zones and choose the one which offers the least resistance to travel. It is assumed that he will use this route continuously unless conditions on the route change or a route with less resistance becomes available.

The usual criteria used to measure travel resistance is travel time. However, travel distance, cost, and various combinations of these criteria have also been used (12). Two methods developed which use travel time as the measure of travel resistance are the all or nothing method and the proportional method.

#### All or Nothing Method

The all or nothing method is the simplest method of traffic assignment. Using this method all interzonal trips are assigned to the route with the minimum travel time between the zones. In a small city where there are few feasible routes between each pair of zones the minimum time route will usually be apparent. After the interzonal trip volumes are assigned to their minimum travel time route the trips on each route are totaled. By comparing the total trip volume with the practical capacity on each route the capacity deficiencies in the transportation system can be determined.

Where there are no signalized intersections the practical capacity of a street is defined as the maximum number of vehicles that can pass a point per hour under prevailing roadway conditions without congestion being so great as to cause unreasonable hazard or delay. Conditions of

the roadway which must be measured to determine practical capacity in these areas are:

1. width of the traffic lanes;
2. lateral clearance between the edge of the pavement and any obstruction;
3. width of the shoulders;
4. per cent of the vehicles using the street which are commercial vehicles;
5. alignment of the roadway; and
6. grade of the roadway.

Where there are signalized intersections the capacity of a route is limited to the capacity of the intersection. The practical capacity of an intersection is defined as the maximum number of vehicles that can pass a point per hour of green time, time the traffic signal is green in the direction capacity is being measured, under existing conditions without the vehicles waiting for more than one complete signal cycle. At an intersection the conditions which must be measured to determine practical capacity are:

1. location of the intersection (downtown, intermediate or outlying);
2. width of intersection;
3. per cent of vehicles using the intersection which are commercial vehicles;



4. parking restrictions at the intersection;
5. per cent of time the signal is green in the direction in which capacity is being measured;
6. bus stops at the intersection;
7. type of operation (one-way or two-way); and
8. turning movements at the intersection.

The methods of determining practical capacity if the roadway or intersection conditions are known are described in the Highway Capacity Manual (13).

The major criticism of the all or nothing method of traffic assignment is that certain routes are assigned no traffic while other routes are loaded beyond their capacity. This is due to the fact that the all or nothing method assumes that all traffic between a pair of zones will use the minimum time route regardless of the congestion on the route. However, J. Douglas Carroll, Jr., Deputy Director of the Tri-State Transportation Committee, has said that this overloading of certain routes has the advantage of magnifying points where improvements in facilities are needed the most (14).

It is the author's opinion that the traffic volume which will use routes other than the minimum time route can be estimated by assigning the volume on the minimum time

route in excess of its capacity to the next best travel time route. Similarly the traffic volume in excess of the capacity of these two routes should be assigned to the third best time route. The assumption is made in assigning this excess traffic to alternate routes, that only the traffic volume in excess of practical capacity on the minimum time route is assigned to other routes. This assumption may be criticized as being unrealistic. However, it is the author's opinion that in a small city where there are few routes between each pair of zones this assumption will be valid and that this extra step will improve the results of the all or nothing method.

#### Proportional Method

The inability of the all or nothing method to assign traffic to routes other than the minimum time route led to the development of the proportional or "capacity restraint" method of assigning interzonal traffic.

Using this method, traffic is assigned to the various routes between a pair of zones in proportion to the inverse of the travel time on the routes.

The following steps are involved in this method.

1. The initial travel time on each route between a pair of zones is determined by dividing the

distance of each route by the route's legal speed limit.

2. All interzonal trips are assigned to the route between each pair of zones having the minimum initial travel time.
3. From the empirically derived capacity function curves shown in Figure 4 on page 36 a new travel time for each route assigned traffic is determined.
4. Assuming that the travel time on the initial minimum time route is the time determined in step 3, the time on all routes between each pair of zones is examined and the minimum time route is again selected. If after changing the time on the initially selected minimum time route it is still the minimum, it is again selected, otherwise, a new route is selected as the minimum time route.
5. The interzonal trips are then assigned to the initially selected route and to the newly selected route between each pair of zones in proportion to the inverse of the travel time on each of the routes.
6. Again the travel time on each of the routes

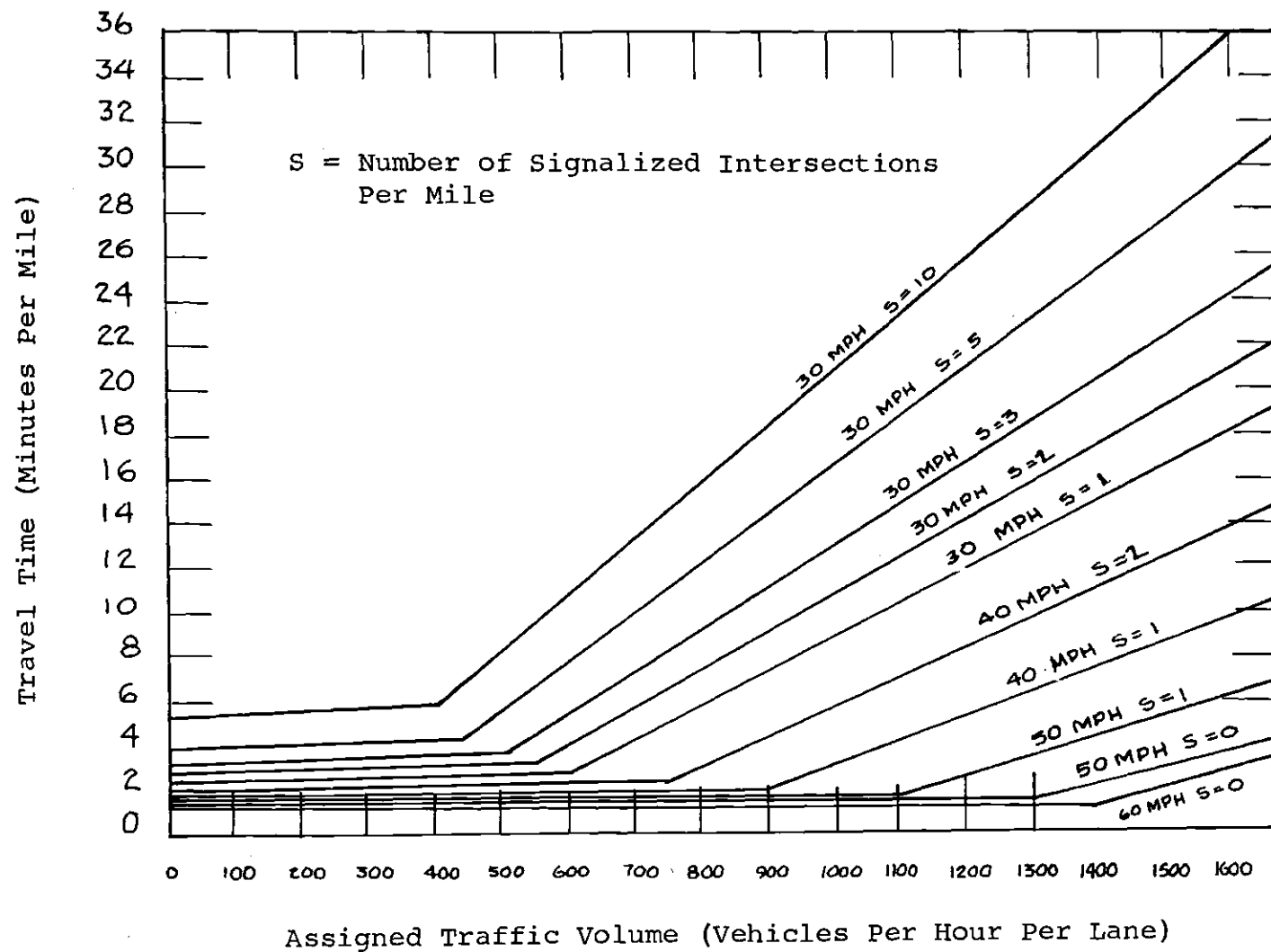


Figure 4. Capacity Function Curves

assigned traffic is revised according to the curves in Figure 4 and the minimum time route between each pair of zones is selected.

7. Trips are again assigned to the new route and to the previously selected routes in proportion to the inverse of the travel time on each route.
8. Steps 6 and 7 are repeated until no new minimum time routes are selected. At this point the traffic volume which last was proportionately assigned to each route is the final assignment.

The proportional assignment method is a more realistic approach to traffic assignment because it expresses the departure of traffic from the minimum time route as traffic volume and hence travel time on it increases. However, it has the disadvantage of not being a simple procedure as is the all or nothing method.

### CHAPTER III

#### MATHEMATICAL MODEL METHOD OF PREDICTING FUTURE TRAFFIC

This chapter will present the second of two methods of predicting future street traffic in the urban area of a small city. This method utilizes a mathematical model for distributing future street traffic. A mathematical model has been defined as " . . . a mathematical statement of observed relationships." (15)

This method does not require a complete origin and destination survey. It is completely applicable in areas which are presently undeveloped but are expected to develop in the future. Unlike the Fratar method, the mathematical model method directly recognizes the effect of travel time on trip making. Computer programs have been written which make computations involved when utilizing the mathematical model method. The main disadvantage of the mathematical model is the attempted application of a mathematical statement to human behavior. That is, the mathematical model attempts to express in a few measureable variables all of the factors a driver considers in making trips. While good results have been attained utilizing models, there is no assurance that

human behavior will follow a predetermined mathematical statement.

The various steps of the mathematical model method are: (1) land use survey; (2) delineation of traffic zones; (3) land use forecast; (4) determination of trip ends; (5) travel time survey; (6) distribution of interzonal trips; and (7) traffic assignment. The land use survey, the delineation of traffic zones, and the land use forecast are performed in the same manner as was described in the preceding chapter. The other steps will be discussed in this chapter.

#### Determination of Trip Ends

The complete origin and destination survey described in the previous chapter provides data on the existing number of interzonal trips and the existing number of trip ends in each zone. Although data on the number of trip ends in each zone are required for the mathematical model method, data on the existing number of interzonal trips are not. In order to save the time and money required for a complete origin and destination survey simplified methods of determining the number of trip ends in each zone have been developed. Two such methods are: (1) the use of a small sample home interview survey; and (2) the use of relationships between trip ends and land use and land use intensity derived

in other cities which have conducted a complete origin and destination survey.

In a recent study made by Bob L. Smith, Associate Professor of Civil Engineering at Kansas State University, the existing number of trip ends in each zone was determined by the complete origin and destination survey as described in the previous chapter (16). A five per cent sample was then selected from the home interview survey and the trip ends in each zone were determined based only on the smaller sample. The number of trip origins and destinations in each zone determined by the small sample were compared with the number determined by the complete origin and destination survey. The study then concluded that existing trip origins and destinations in each zone are adequately estimated from a small sample home interview survey.

Once the existing number of trip ends in each zone have been determined by the above method, the relationships between trip ends and land use and land use intensity should be determined by the method described in the Trip Generation section of the previous chapter. These relationships should then be applied to a forecast of future land use and land use intensity to determine the future number of trip ends in each zone.



The second simplified method of determining trip ends in each zone is the use of relationships between trip ends and land use and land use intensity derived in some other city which has made an origin and destination survey. Using this method, these relationships are applied directly to the future land use and land use intensity to determine future trip ends. A study conducted by the Missouri Highway Department used this method to determine future trip ends in Cape Girardeau (17). The relationships used in this study were derived in Joplin, Missouri. The Iowa Highway Department has also utilized this method. Future trip ends in six Iowa cities were estimated from the relationships derived in Cedar Rapids (18).

#### Travel Time Survey

The purpose of the travel time survey is to determine the time it takes to travel between each pair of traffic zones. Several possible methods can be used to determine travel time. However, the method most often used and the one which gives the best results is the floating car method (19).

Persons collecting data by the floating car method drive an automobile in traffic on each street for which travel time data are desired. The driver maintains

approximately the same speed as the traffic around him and passes the same number of cars that pass him. An observer in the car records the time it takes to travel between all major intersections. This process is repeated several times and the average time between each intersection is recorded and used as the travel time for that section of the street. The data should be collected during the peak hour on a day when traffic is not abnormal, preferably Tuesday, Wednesday or Thursday.

#### Distribution of Interzonal Trips

After the future number of trip ends in each zone and the travel time between each pair of zones have been estimated, it will be necessary to distribute future interzonal trips. A separate distribution of interzonal trips should be made for each trip purpose category.\*

Two mathematical models which have been developed to distribute interzonal trips are the gravity model and the competing opportunities model.

#### Gravity Model

The gravity model for distributing interzonal trips

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\* Trip purpose categories are described in the Trip Generation section of the previous chapter.

was developed by Alan Voorhees of Alan Voorhees and Associates, Inc., transportation planning consultants (20). It adapts the gravitational theory, advanced by Isaac Newton in 1686, to the problem of traffic distribution. The theory can generally be stated in the following manner. The number of trips made between a pair of zones is directly proportional to the trip attraction of each zone and inversely proportional to the travel time between these zones. That is, trips are generally made to the most attractive of the possible destinations which have the minimum travel time. Specifically, the trips originating in each zone are distributed to each other zone in proportion to the product of the number of trip destinations in the zone and the travel time factor for the zone, relative to the products of the trip destinations and the travel time factor for all zones to which trips are being distributed. Travel time factors express the average area-wide effect of physical separation between zones on interzonal trips. Mathematically the gravity model can be written as follows:

$$T_{(i-j)} = P_i \frac{A_j F_{(i-j)}}{\sum_{j=1}^n A_j F_{(i-j)}} \quad (1)$$

Where:  $i$  = The zone from which trips are being distributed.

$j$  = The zone to which trips are being distributed.

$T_{(i-j)}$  = Trips going from zone  $i$  to zone  $j$ .

$P_i$  = Trip origins in zone  $i$ .

$A_j$  = Trip destinations in zone  $j$ .

$F_{(i-j)}$  = Travel time factors for trips between zone  $i$  and zone  $j$ .

In order to calculate the number of interzonal trips it is necessary to determine the following:

1. the number of trip origins in each zone, designated in the formula by  $P_i$ ;
2. the number of trip destinations in each zone, designated in the formula by  $A_j$ ;
3. a travel time factor for each pair of zones, designated in the formula by  $F_{(i-j)}$ .

The number of origins and destinations in each zone is estimated utilizing the method described in the Determination of Trip Ends section of this chapter.

Travel time factors are determined for the travel time between each pair of zones from the empirically derived curves for each trip purpose shown in Figures 5, 6 and 7 on

pages 46, 47 and 48 respectively. These curves were derived in a transportation study made under the direction of the Bureau of Public Roads in Hutchinson, Kansas (21). Charles F. Barnes, Jr., an associate with Alan Voorhees and Associates, states that since travel time factor curves are so nearly similar nationwide very little error would be introduced by using travel time factor curves from other cities (22)\*.

To summarize, the steps in distributing trips by the gravity model and a simple example illustrating the use of these steps will be presented.

Consider the simple three zone situation shown in Figure 8 on page 49 with the necessary data given in Table 2.

Table 2. Known Data in the Example Situation

Zone	Estimated	Estimated	Travel Time	
	Future Trip Origins	Future Trip Destinations	Between Zones	Travel Time
A	25	25	A-B	14
B	40	40	B-C	20
C	45	45	A-C	6.5

\* Should a city prefer to derive its own curves rather than use those presented here, the method of deriving them is described in reference 23. The derivation of these curves requires that data from an origin and destination survey be available.

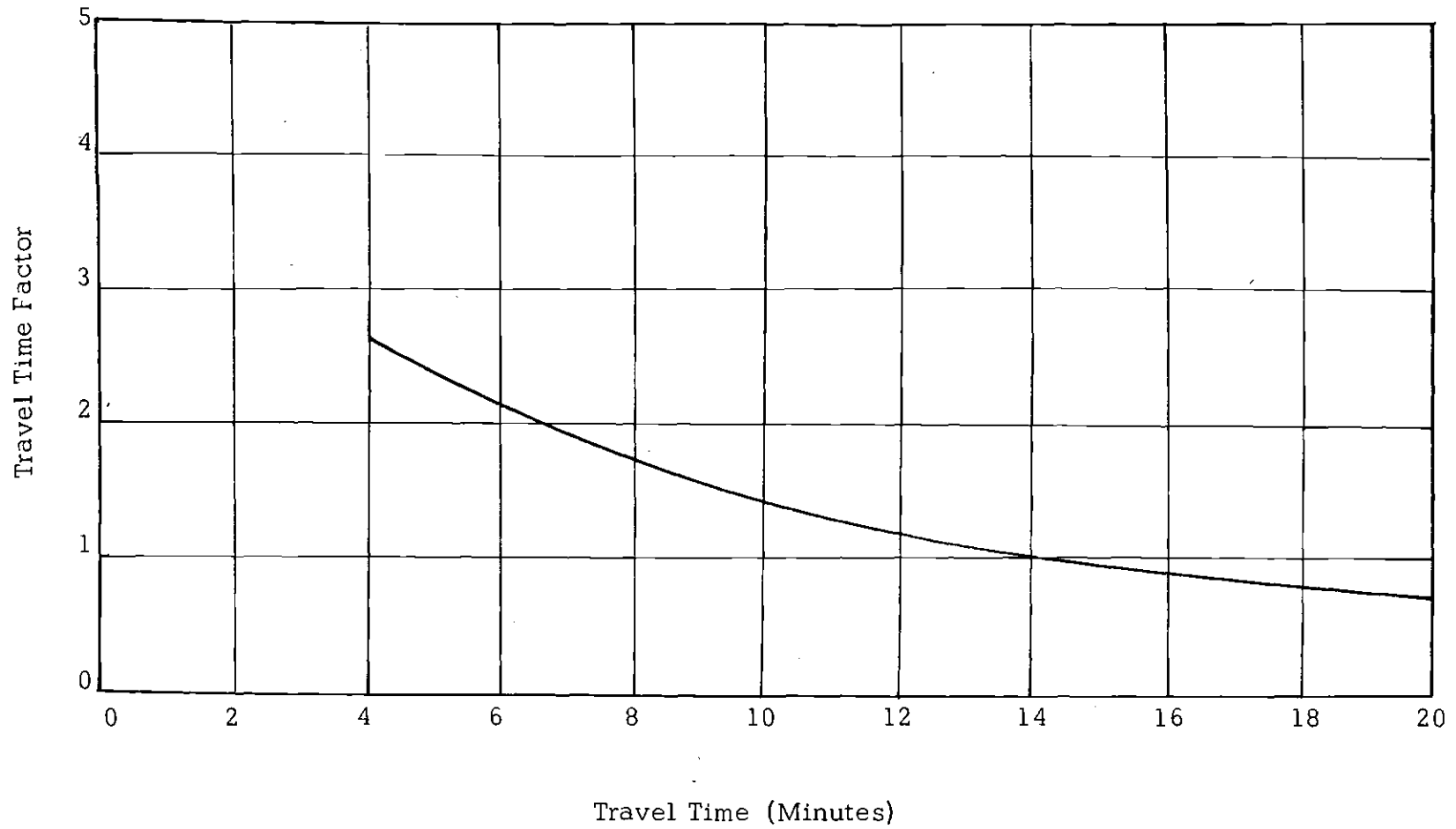


Figure 5. Travel Time Factor Curve For Home Work Trips

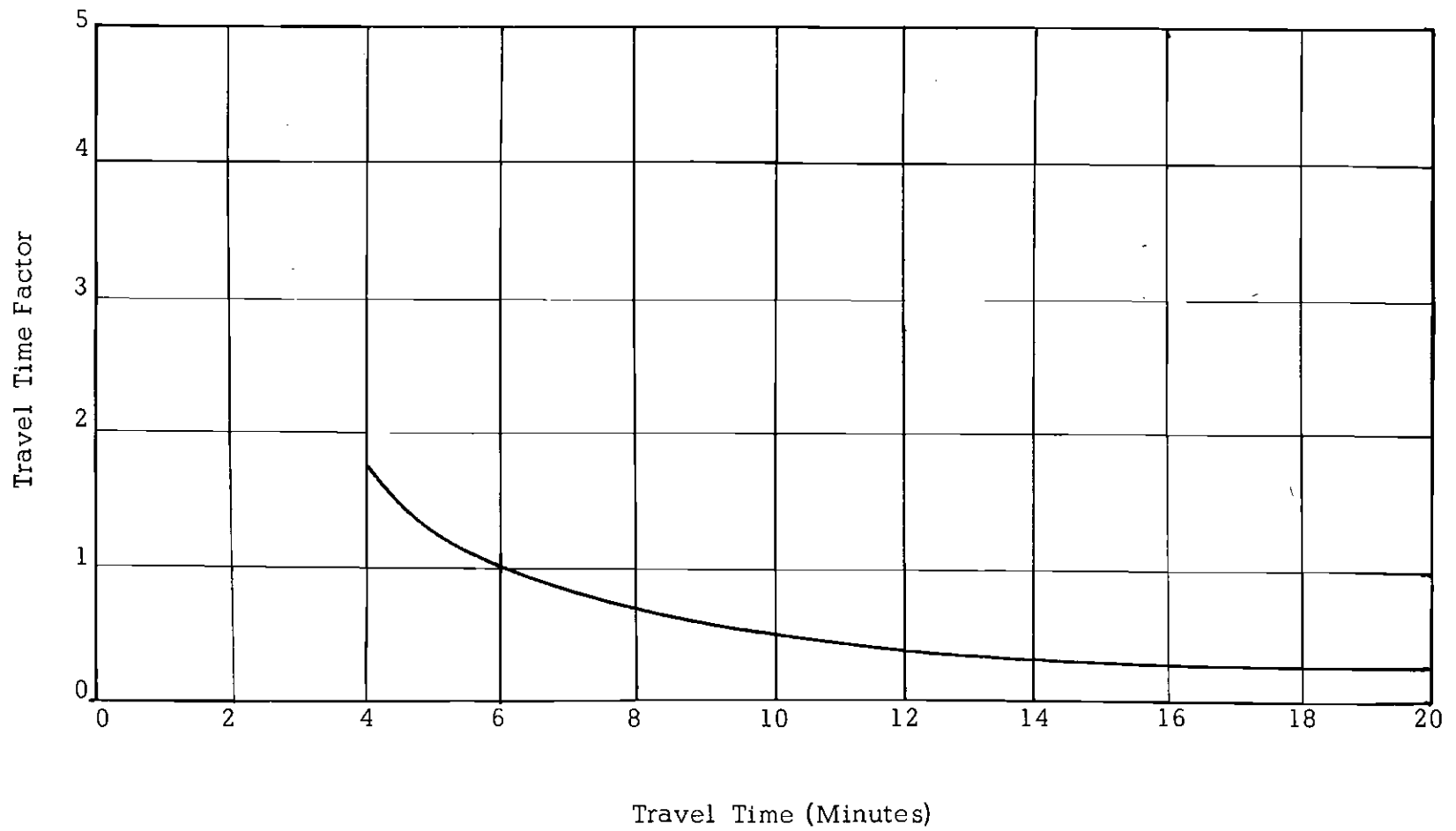


Figure 6. Travel Time Factor Curve For Home Non-Work Trips

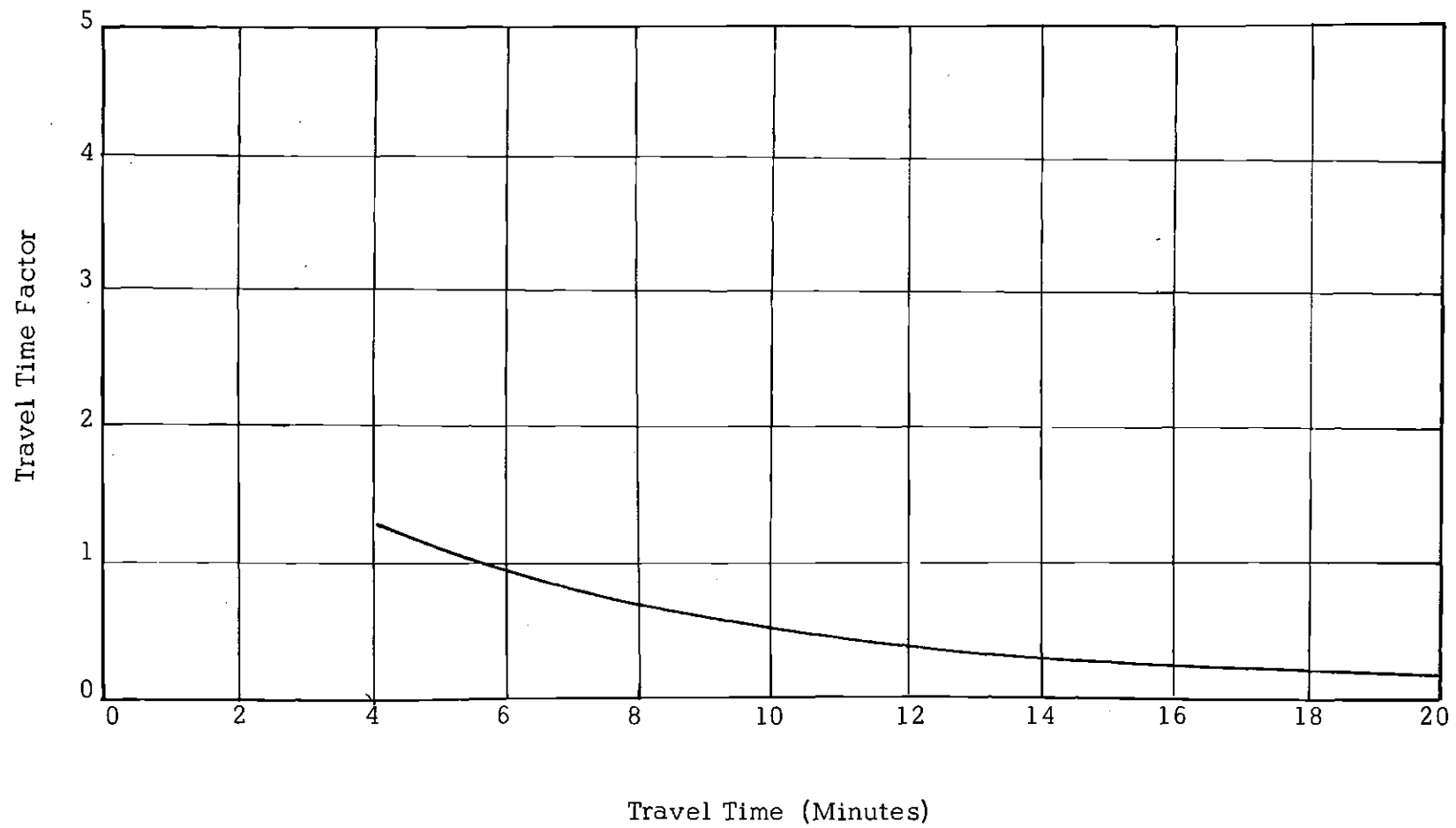


Figure 7. Travel Time Factor Curve For Non-Home Trips



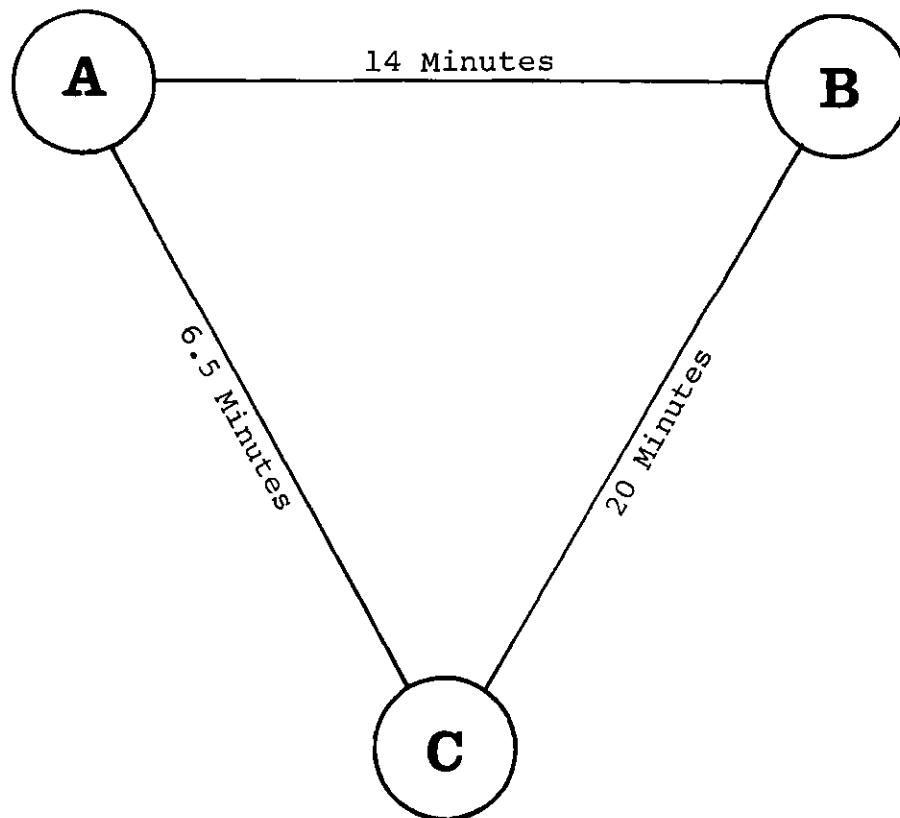


Figure 8. Travel Time Between Zones in the Example

The following steps are used to distribute interzonal trips using the gravity model.

1. Determine the travel time factor for the travel time between each pair of zones from the curves in Figures 5, 6 and 7.

From Figure 5 (assuming that home based work trips are being distributed) the travel time factors will be:

Between Zones A and B = 1.00

Between Zones B and C = .50

Between Zones A and C = 2.00

2. Determine the attractiveness each zone has for trips from each other zone by multiplying the number of trip destinations in each zone by the travel time factor corresponding to the travel time between it and the zone from which trips are being distributed.

The attractiveness values for the zones in the example are as follows:

Attractiveness Zone A has for trips from;

$$\text{Zone B} = 1.0 \times 25 = 25$$

$$\text{Zone C} = 2.0 \times 25 = 50$$

Attractiveness Zone B has for trips from;

$$\text{Zone A} = 1.0 \times 40 = 40$$

$$\text{Zone C} = 0.5 \times 25 = 20$$

Attractiveness Zone C has for trips from;

$$\text{Zone B} = 0.5 \times 45 = 22.5$$

$$\text{Zone A} = 2.0 \times 45 = 90$$

3. Sum the products of the trip destination and the travel time factors found in steps (2) for all of the zones which have a trip interchange with the zone from which trips are being distributed.

For trips from each zone in the example the sums are as follows:

$$\text{Zone A the Sum} = 40 + 90 = 130$$

$$\text{Zone B the Sum} = 25 + 22.5 = 47.5$$

$$\text{Zone C the Sum} = 50 + 20 = 70$$

4. Determine the proportion of trip origins that will be distributed from each zone to each other zone by dividing the product of the trip destination and the travel time factor for the zone in question by the sum of the products determined in step (3).

Proportion of trip origins in each zone going to each other zone in the example is as follows:

$$\text{Zone A to Zone B} = \frac{40}{130} = .31$$

$$\text{to Zone C} = \frac{90}{130} = .69$$

$$\text{Zone B to Zone A} = \frac{25}{47.5} = .53$$

$$\text{to Zone B} = \frac{22.5}{47.5} = .47$$

$$\text{Zone C to Zone A} = \frac{50}{70} = .71$$

$$\text{to Zone B} = \frac{20}{70} = .29$$

5. Determine the number of trips distributed to each zone by multiplying the total trip origins in the zone from which trips are being distributed by the proportion of trips going to each other zone.

The number of trips from each zone to each other zone in the example is as follows:

$$\text{Zone A to Zone B} = 25 \times .31 = 8$$

$$\text{to Zone C} = 25 \times .69 = 17$$

$$\text{Zone B to Zone A} = 40 \times .53 = 21$$

$$\text{to Zone C} = 40 \times .47 = 19$$

$$\text{Zone C to Zone A} = 45 \times .71 = 32$$

$$\text{to Zone B} = 45 \times .29 = 13$$

#### Competing Opportunities Model

The competing opportunities model for distributing interzonal trips was developed by Anthony Tomazinis, Assistant Professor of City Planning at the University of Pennsylvania, to analyze 1960 origin and destination data gathered by the Penn-Jersey Transportation Study (24). The basic concept of this method is that the probability that a trip will go to a zone depends on the ratio of the trip opportunities in that zone to the competing opportunities within the same travel time from the zone of origin. The number of opportunities in a zone is equal to the number of trip destinations in the zone.

Using the competing opportunities model the number of trips distributed from one zone to another is equal to the

total trip origins in the zone from which trips are being distributed multiplied by the adjusted probability of trips being attracted to that zone. This is expressed mathematically as follows:

$$T_{ij} = T_i P'_j \quad (2)$$

Where:  $T_{ij}$  = Trips originating in zone i and terminating in zone j.

$T_i$  = Number of trips originating in zone i.

$P'_j$  = The adjusted probability of trips going from zone i to zone j.

The number of future trip origins and destinations in each zone is estimated utilizing the methods discussed in the Determination of Trip Ends section of this chapter.

In order to determine the adjusted probability it is necessary to draw a series of concentric rings around the center of the zone from which trips are being distributed. An example of such a series of rings is shown in Figure 9 on page 55.

These rings represent various units of travel time from the zone in question. These units can be 2, 3, 6, or any time interval, in minutes, apart. The area inclosed by each successive ring is known as a time code. For example,

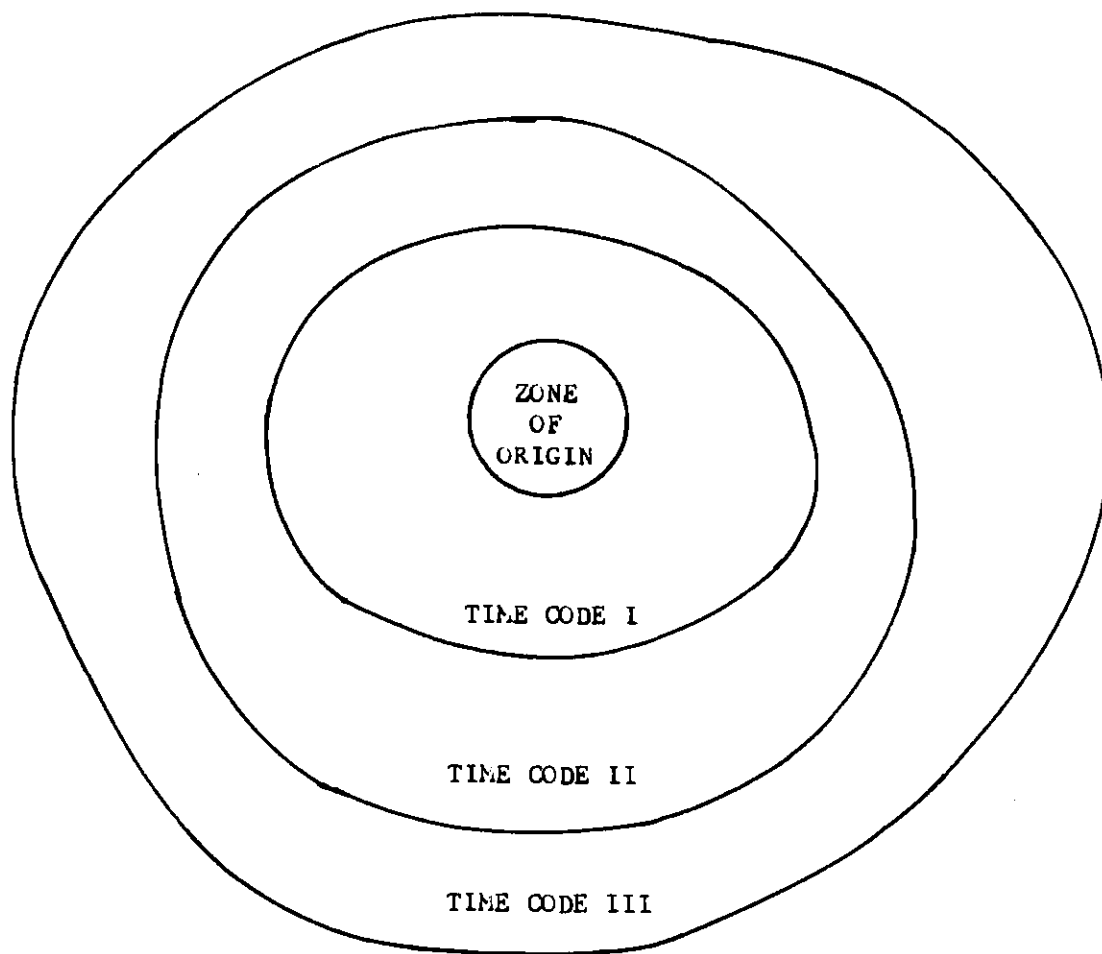


Figure 9. Example of Time Codes

the area in time code one might include the area within two minutes travel time from the center of the zone of origin, the area in time code two would then be the area within four minutes travel time of the zone in question, and the area in time code three would be the area within six minutes travel time from the zone of origin. Therefore, all zones in the urban area will lie within some time code of the zone of origin. A zone is considered to lie in the time code in which the center of the zone lies. The longer the travel time between a zone of origin and a zone destination the larger is the number of other zones which are also included in the same time code. This is the basis of the competing opportunities model. The farther in travel time a zone of destination is from a zone of origin the more competition it has from other zones of destination in attracting trips. The probability of a trip going from zone  $i$  to zone  $j$  is equal to the number of destinations at zone  $j$  divided by the total destinations in the time code in which zone  $j$  lies. This is expressed mathematically as follows:

$$P_j = \frac{D_j}{D_t} \quad (3)$$



Where:  $D_j$  = The number of trip destinations in  
zone  $j$ .

$D_t$  = The total trip destinations in the time  
code in which zone  $j$  lies.

$P_j$  = Probability of a trip being attracted  
from zone  $i$  to zone  $j$ .

For each zone of destination in the urban area the probability of attracting trips from zone  $i$  can be calculated. However, the probabilities will have to be adjusted in order that the sum of all the probabilities will be equal to 1.00. The adjusted probability is determined by dividing each probability by the sum of the probabilities over the entire urban area. That is:

$$P'_j = \frac{P_j}{\sum_{K=1}^n P_K} \quad (4)$$

Where:  $j$  = zone to which trips are being distributed.

$k$  = all zones to which trips are being distributed including zone  $j$ .

$P'_j$  = adjusted probability of a trip being attracted from zone  $i$  to zone  $j$ .

$P_j$  = probability of a trip being attracted from zone i to zone j.

$\sum_{K=1}^n P_K$  = the sum of all the probabilities of attracting trips from zone i over the entire area.

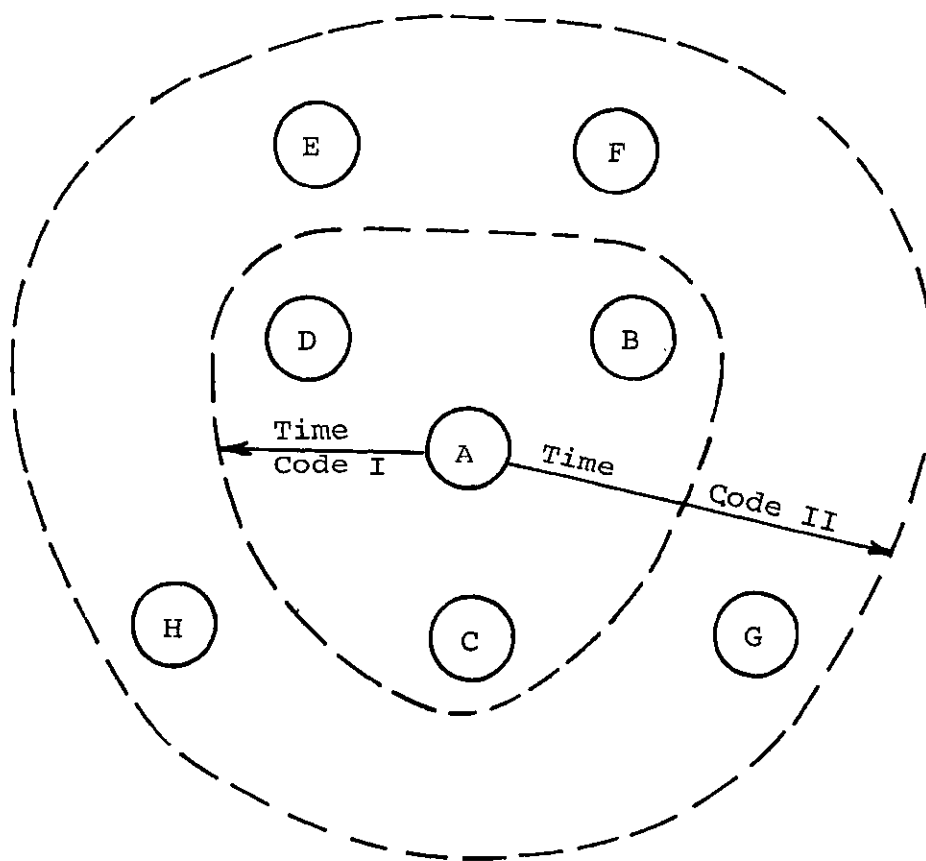
After the adjusted probability ( $P'_j$ ) is determined for each zone as described above, it can be used in Equation (2) to determine future interzonal trips.

To summarize the competing opportunities model the steps in distributing trips and a simple example illustrating the use of these steps will be presented.

Consider the situation shown in Figure 10 on page 59 with the necessary data given in Table 3.

Table 3. Known Data in Example Situation

Time Code			Time Code		
I			II		
Zone	Future Trip Destinations		Zone	Future Trip Destinations	
B	10		B	10	
C	20		C	20	
D	<u>15</u>		D	15	
Total	45		E	10	
			F	5	
			G	20	
			H	<u>15</u>	
			Total	95	



Total Trip Origins in Zone A Equals 30

Figure 10. Location of Zones with Respect to the Time Codes of Zone A

The steps in distributing trips by the competing opportunities model are as follows:

1. Delineate a series of time codes around each zone based on travel time from the center of the zone.

The time code for Zone A of the example are shown in Figure 10.

2. Determine the total trip destinations in each time code by adding the destinations in all zones within each time code.

Totals for the example problem are tabulated in Table 3.

3. Determine the probability of each zone attracting trips from the zone from which trips are being distributed by dividing the trip destinations in each zone by the total destinations in the same time code.

The probability of each zone attracting trips from Zone A in the example is as follows:

Zone B = $10/45 = .22$	Zone E = $10/45 = .10$
Zone C = $20/45 = .44$	Zone F = $5/95 = .05$
Zone D = $15/45 = .34$	Zone G = $20/95 = .21$
Total 1.00	Zone H = $15/45 = .16$
	Total .52

4. Determine for each zone the adjusted probability of attracting trips from each other zone by dividing the probability of the zone in question by the sum of the probabilities of all the zones.

The sum of all the probabilities in the example is 1.52 and the adjusted probability of each attracting trips from Zone A of the example is as follows:

$$\text{Zone B} = .22/1.52 = .15$$

$$\text{Zone C} = .44/1.52 = .29$$

$$\text{Zone D} = .34/1.52 = .22$$

$$\text{Zone E} = .10/1.52 = .07$$

$$\text{Zone F} = .05/1.52 = .03$$

$$\text{Zone G} = .21/1.52 = .14$$

$$\begin{array}{rcl} \text{Zone H} & = & .16/1.52 = \underline{.10} \\ & & \text{Total} \quad 1.00 \end{array}$$

5. Determine the number of trips that will be distributed from each zone to each other zone by multiplying the number of trip origins in each

zone by each other zone's adjusted probability of attracting trips from it.

The number of trips distributed to each zone from Zone A of the example is as follows:

$$\text{Zone B} = 30 \times .15 = 5 \text{ Trips}$$

$$\text{Zone C} = 30 \times .29 = 8 \text{ Trips}$$

$$\text{Zone D} = 30 \times .22 = 7 \text{ Trips}$$

$$\text{Zone E} = 30 \times .07 = 2 \text{ Trips}$$

$$\text{Zone F} = 30 \times .03 = 1 \text{ Trip}$$

$$\text{Zone G} = 30 \times .14 = 4 \text{ Trips}$$

$$\text{Zone H} = 30 \times .10 = 3 \text{ Trips}$$

$$\text{Total} \quad \overline{30} \text{ Trips}$$

The same process as described above should be repeated for each zone in the urban area.

### Traffic Assignment

The all or nothing and the proportional methods of traffic assignment as applied to the Fratar method are also applicable to the mathematical models. In addition, the proportional method can be carried another step in utilizing

the mathematical model methods of trip distribution. This additional step involves a feedback of the new travel times on each route to the mathematical model used to distribute interzonal trips. The determination of the new travel time was discussed in Step 6 of the proportional assignment method on page 35 in the previous chapter. A new distribution of interzonal trips is made based on the new travel times. This new distribution of trips is again assigned to the various streets by the proportional method. If the travel times on each route determined in the second assignment are not approximately equal to travel times used in the redistribution of interzonal trips the feedback step can again be repeated.

This method of traffic assignment was developed by the Traffic Research Corporation while preparing a transportation plan for Toronto in 1960 (25). The flow diagram shown in Figure 11 on page 64 illustrates the process.

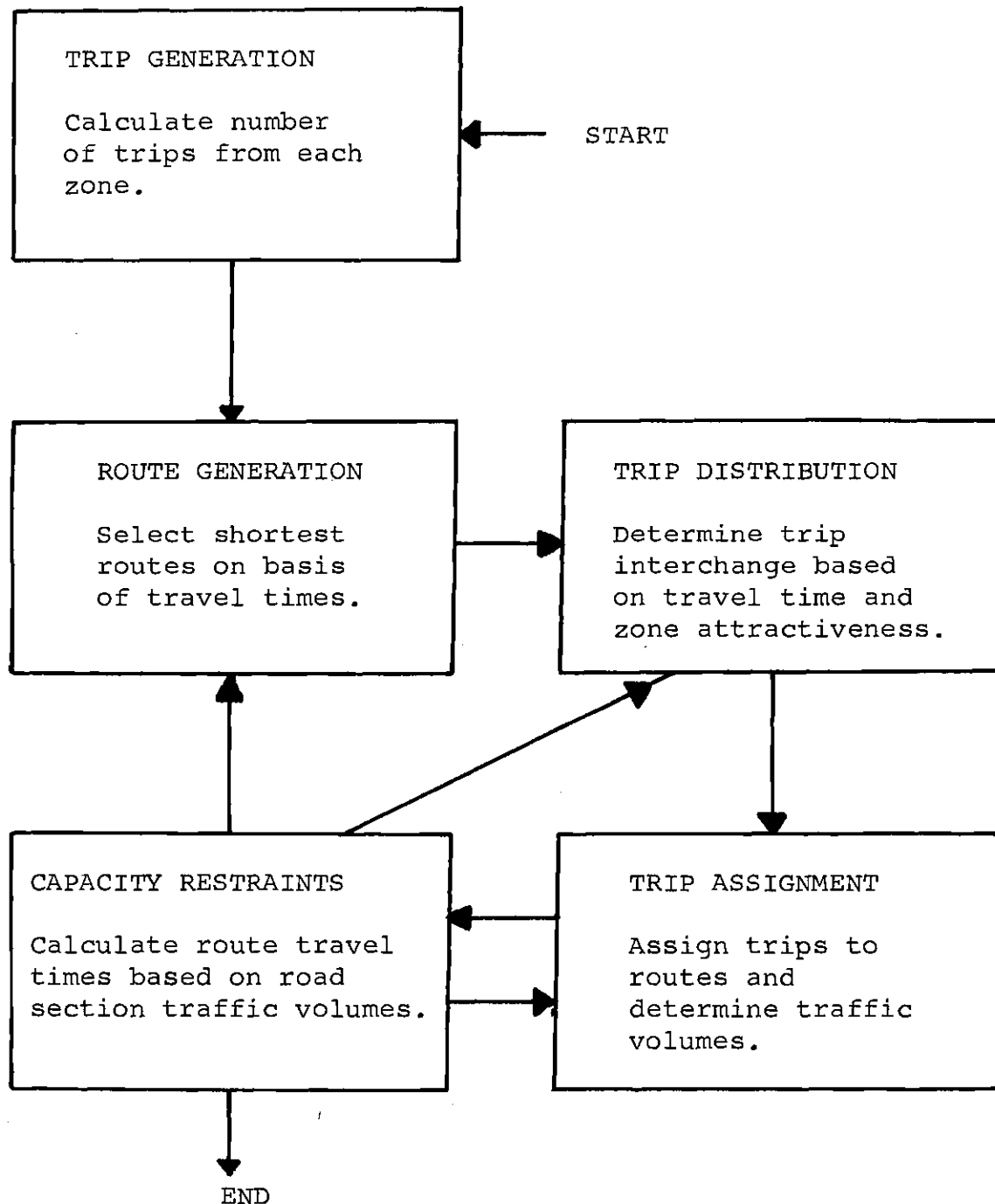


Figure 11. Flow Chart



## CHAPTER IV

### SUMMARY

The increase in traffic volumes on the street systems in urban areas has created the need for construction of new streets and highways and the improvement of existing ones. Accurate prediction of future traffic volumes is an essential step in the planning of new facilities and of improvements to existing ones.

In recent years methods of predicting traffic have been developed in the transportation studies of large metropolitan areas. This thesis has discussed the application of these methods to cities under 100,000 in population. The methods presented are the Fratar method and the mathematical model method.

The first method discussed utilizes the Fratar technique for distributing future interzonal trips. The utilization of this method requires a complete origin and destination survey. This method does not yield good results in cities which have large undeveloped areas which are expected to be developed in the future. The various steps of the Fratar method are: (1) land use survey; (2) origin and

destination survey; (3) trip generation; (4) land use forecast; (5) distribution of interzonal trips; and (6) traffic assignment.

The mathematical model method utilizes a mathematical model for distributing future interzonal trips. Two models presented are the gravity model and the competing opportunities model. The author could find no evidence that one of these models is more correct theoretically than the other. However, the gravity model, because of its earlier development, has been utilized much more than the competing opportunities model. The experience gained in the gravity model's wider use has made possible many refinements in the procedures involved with its application.

The mathematical model method does not require a complete origin and destination survey. It is applicable in areas which are presently undeveloped but are expected to develop in the future. Unlike the Fratar method, the mathematical model method directly recognizes the effect of travel time on trip making. The main disadvantage of the mathematical model is that there is no assurance that the model can adequately describe the many variables that influence a driver's decision to choose one destination over another. The various steps of the mathematical model method

are: (1) land use survey; (2) delineation of traffic zones; (3) land use forecast; (4) determination of trip ends; (5) travel time survey; (6) distribution of interzonal trips; and (7) traffic assignment.

Computer programs have been written for making the mathematical computations involved when utilizing either the Fratar or the mathematical model methods. These programs are available for most of the computers being used today.

The methods of predicting traffic presented in this thesis can and should be used in small cities. Predictions based on these methods should serve as a guide to major street planning.

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